TABLE OF CONTENTS

EXECUTIVE SUMMARY . . . . . *iv*

1.0 RESEARCH GOALS 1-1

1.1 Introduction to the Research Plan 1-1

1.2 Estero Bay and Bay Science 1-2
1.2.1 Geography 1-3
1.2.2 Geology 1-3
1.2.3 Hydrology 1-3
1.2.4 Hydrography 1-4
1.2.5 Sediments 1-4
1.2.6 Fresh Water and Salinity 1-4
1.2.7 Water Quality 1-5
1.2.8 Ecology 1-5
1.2.9 Management 1-5
1.2.10 Inferences and Conclusions 1-6

1.3 Research Goals 1-6
1.3.1 On the Nature of Goals in Research 1-6
1.3.2 Existing Authorities 1-7
1.3.3 Assessment of Authorities 1-23

1.4 Recommended Goals for the Estero Bay Research Plan 1-25
1.4.1 Remarks 1-25
1.4.2 Recommended Goals 1-27

2.0 RESEARCH QUESTIONS 2-1

2.1 Introduction to the Research Plan 2-1

2.2 Research Questions and Their Rationale 2-3
2.2.1 On the Nature of Research Questions 2-3
2.2.2 On Segmentation 2-4
2.2.3 Two Types of Research Questions 2-5
2.2.4 Status and Trend Questions 2-5
2.2.5 Causal Process Questions 2-8

2.3 Synthesis 2-10
2.3.1 Status and Trend Questions 2-10
2.3.2 Causal Process Questions 2-12
2.3.3 Technical Rationale for Research Questions 2-12
2.3.4 Assessment 2-16

2.4 Discussion 2-17
2.4.1 Estero Bay Agency on Bay Management 2-17
2.4.2 Chapter 3 Preview 2-18

3.0 RESEARCH PLAN 3-1

3.1 Introduction to the Research Plan 3-1

3.2 Research Methods and Their Rationale 3-5

3.3 Descriptions and Critiques 3-7
3.3.1 Standards 3-7
3.3.2 Trend Analysis 3-8
3.3.3 Indices 3-9

3.4 Synthesis 3-39

3.5 Discussion 3-42

3.6 Chapter 4 Preview 3-43

4.0 RESEARCH GOALS, QUESTIONS, METHODS AND PROJECT SCOPES 4-1

4.1 Introduction to the Research Plan 4-1

4.2 Estero Bay and Bay Science 4-1
4.2.1 Geography 4-2
4.2.2 Geology 4-2
4.2.3 Hydrology 4-3
4.2.4 Hydrography 4-3
4.2.5 Sediments 4-3
4.2.6 Fresh Water and Salinity 4-4
4.2.7 Water Quality 4-4
4.2.8 Ecology 4-4
4.2.9 Management 4-5
4.2.10 Inferences and Conclusions 4-5

4.3 Part I - Estero Bay Authorities, Valued Ecosystem Components and Goals 4-6

4.4 Part II - Research Questions and Their Rationale 4-15

4.5 Part III - Research Methods and Their Rationale 4-21

4.6 Part IV - Recommended Research Projects 4-27

4.7 The Estero Bay Research Plan - Acronyms, Definitions, and Notes 4-30

4.8 The Estero Bay Research Plan 4-32
4.8.1 SAV History and Trend Analysis 4-32
4.8.2 Molluscan History and Trend Analysis 4-34
4.8.3 Oligohaline Habitat History and Trend Analysis 4-37
4.8.4 History and Trend Analysis for VEC Stressors 4-40
4.8.5 Ecological Studies of SAV Production and Regulation 4-43
4.8.6 Ecological Studies of Shellfish Production, Regulation, and Sanitation 4-45
4.8.7 Sedimentology 4-47
4.8.8 Bay Water Quality Model 4-49

5.0 REFERENCES 5-1

APPENDICES

Appendix I. Quality Assurance

Appendix II. Data Management

EXECUTIVE SUMMARY

In 1997, the South Florida Water Management District undertook an Estero Bay and Watershed Management and Improvement Plan, a multi-year project. The Estero Bay Assessment will define water quality and water quantity objectives for the Bay and develop tools to evaluate the effects of watershed management. The Bay Assessment involves the application of a logical protocol for designing study plans, to identify the types of pollutants and their impacts on estuarine environments. The first and present phase of the assessment will result in an Estero Bay Research Plan, based on management goals for the estuary. A subsequent assessment phase implements the research plan.

The Research Plan follows a method developed for study of the St. Lucie River and estuary. First, goals are established for the Bay. Next, research questions appropriate to each goal are identified. Finally, specific analytical methodologies are defined to answer each research question. Taken as a whole, these tasks will comprise the Estero Bay Research Plan. This report provides a summary of prior reports on goals, and research questions and methods. Part IV of this report is comprised of detailed outlines for a number of particular research projects.

Estero Bay is not a data-deficient system, but there exists a number of subjects for which data are insufficient to support analytical assessments of cause and effect, or to support predictions of Bay response to proposed changes, including restoration or mitigation. Much less seems known of the southern Bay than other reaches. Most sources feel the bay is in good shape, or just beginning to manifest symptoms of decline. Compared to many other bays with active management programs, there are few well-documented problems to fix. Science in Estero Bay will not be driven so much by problem resolution, as by the need to understand basic processes affecting resources of value.

Valued ecosystem components of Estero Bay were identified from a review of 25 authorities, as well as from general estuarine ecology and experiences of other Florida bay management programs. Estero Bay authorities refer to numerous living resources and ecosystem components, as well as ecosystem processes that underlie biotic resources, in particular a natural hydroperiod, and high water quality. For purposes of defining goals, valued ecosystem components used in this analysis include submerged aquatic vegetation, shellfish, and oligohaline habitats.

Social expectations for Estero Bay are very high, and go far beyond maintenance of the status quo. The Bay is a state Aquatic Preserve (Florida's first) and Outstanding Florida Water (OFW). The State of Florida intends that the aquatic preserve be managed for wilderness purposes. The OFW designation requires that no degradation of water quality be allowed. The South Florida Water Management District gave Estero Bay the highest ranking among estuaries for SWIM status, as a preservation priority. Lee County seeks to meet all established pollution load reduction goals for the Bay, and to work toward Class II (waters of the state) classification-- meaning that shellfish waters would be opened. Numerous authorities codify an intent to establish natural, historic, or pre-development conditions with respect to hydrology and water quality.

Proposed goals are likely to be affected significantly by the Bay's geology and shallow depth. Geological structures and processes (including mangroves) in the bay, watershed, and inshore shelf are [probably] the dominant regulators of Estero Bay's hydrology, water quality, and ecology. Impacts of stressors (altered freshwater inflow, nutrient loadings, contaminants) or trends in valued ecosystem components (seagrasses, fish and wildlife) can be understood and managed only by understanding factors which control the Bay's geomorphology.

Goals recommended for the development of the Estero Bay Research Plan are given below. Goals are hierarchically ordered, with primary goals based on management end-points for valued ecosystem components. Secondary goals address recommended changes to VEC stressors, and tertiary goals map causal mechanisms into management decisions regarding the quantity and quality of freshwater inflows.

1.0. Restore the area, location, species composition, and condition of submerged aquatic vegetation (SAV-- sea grasses, rooted macrophytic algae) to pre-development conditions.

1.1. Bring proximate stressors of SAV (light, turbidity, salinity, exposure, biotic regulators, etc.) into ranges suitable for natural recolonization within areas of SAV extirpation.

1.1.1. Modify quantity and quality of freshwater inflows (surface water, ground water) as needed to relieve proximate stressors, within the context of natural geologic conditions in the Bay.

2.0. Create conditions of water quality necessary to increase the area of Estero Bay designated as Class II (shellfish propagation or harvesting) waters of the State, and permit some area of the Bay to be classified "approved" for shellfish consumption.

2.1. Bring proximate stressors of shellfish productivity and sanitation (pathogens, turbidity, salinity, exposure, biotic regulators, etc.) into ranges suitable for shellfish propagation and harvesting.

2.1.1. Modify quantity and quality of freshwater inflows (surface water, ground water) as needed to relieve proximate stressors, within the context of natural geologic conditions in the Bay.

3.0. Register the location, size, and duration of oligohaline habitat (salinity less than 10 parts per thousand) to pre-development conditions.

3.1. Modify quantity and timing of freshwater inflows as needed, within the context of natural geologic conditions in the Bay.

Each of the three primary goals is meaningful in the context of Bay management. Each is verifiable through empirical measurement, and each is practical (achievable with existing technology). Primary goals address primary and secondary producers at the species, community, and habitat levels of biological organization. Each is traceable through intermediate goals to major management issues of freshwater inflow, and water quality.

Part II identified necessary and sufficient research questions for each of the eight goals. A total of 58 questions was posed, of two forms Thirty-seven questions sought to establish status and trends for three valued ecosystem components (VEC): submerged aquatic vegetation (SAV); shellfish, and

oligohaline (low-salinity) habitats. Twenty-one questions sought to establish the types and forms of causal processes relating VEC to stressors, and stressors to controlling factors. Questions were combined to create a final list of 10 status and trend questions (STQ) and 9 causal process questions (CPQ), which are:

Status and Trend Questions

STQ. 1. What was the pre-development status of valued ecosystem components, in terms of:
- SAV area, location, species composition, and condition,
- molluscan shellfish diversity, abundance, and sanitation; and,
- oligohaline habitat area, location, species composition, and condition?

STQ. 2. What changes in valued ecosystem components have occurred from pre-development to modern time, in terms of:
- SAV area, location, species composition, and condition,
- molluscan shellfish diversity, abundance, and sanitation; and
- oligohaline habitat area, location, species composition, and condition?

STQ. 3. What are the geographic and seasonal distributions (and other statistical properties) of measured values for the following stressors regulating valued ecosystem components, *specifically for open Bay waters:*
- water temperature, salinity, light attenuation, color, chlorophyll, mineral and organic turbidity, nutrients, current speed, wave energy, sediment structure, and tidal exposure values (for SAV); and
- also pathogen type and abundance, and dissolved oxygen (for shellfish)?

STQ. 4. How have statistical descriptors of present-day stressors changed over the period of available data, for SAV and shellfish in the Bay?

STQ. 5. What are the ranges, statistical distributions, and seasonal and spatial variations of present-day fresh water flow to the Bay, in terms of:
- direct precipitation,
- gaged surface water discharge via waterways,
- ungaged surface water discharge via waterways,
- sheet flow,
- water table and surficial aquifers,
- confined aquifers; and
- permitted point and non-point source discharges.

STQ. 6. How have statistical descriptors of present-day fresh water flow changed over the period of available data?

STQ. 7. What are the geographic and seasonal distributions (and other statistical properties) of measured values for the following stressors regulating valued ecosystem components, *specifically for fresh water flowing to the Bay?*
- water temperature, salinity, light attenuation, color, chlorophyll, mineral and organic turbidity, nutrients, current speed, sediment structure, and oxygen demand values (for SAV); and

. also pathogen type and abundance, and dissolved oxygen (for shellfish)?

STQ. 8. How have statistical descriptors of present-day SAV and shellfish stressors changed over the period of available data, in fresh waters flowing to the Bay?

STQ. 9. What are the present-day spatial characteristics of Bay sediments with respect to:
. age, provenance, transport, and deposition,
. thickness, granulometry, and mineral composition,
. organic content and oxygen demand; and
. anthropogenic contaminant concentrations?

STQ. 10. What changes in sediment characteristics have occurred in recent times?

Causal Process Questions

CPQ. 1. What major physical changes have occurred in the study area, in terms of:
. topography of the watershed; and
. bathymetry of the Bay, its tributaries, or Gulf connections?

CPQ. 2. What are the present-day seasonal requirements and limits of valued ecosystem components (species diversity, shoot density, biomass, net production, etc. for SAV; diversity, abundance, and bacterial contamination of shellfish; area, location, and species composition of oligohaline habitat), in statistically significant terms of the following stressors:
. freshwater supply and tidal action (for oligohaline habitat),
. water temperature, salinity, light availability, nutrients, current speed, wave energy, sediment structure, and tidal exposure values (for SAV); and
. also pathogen type and abundance, and dissolved oxygen (for shellfish)?

CPQ. 3. Is physical recruitment a significant factor limiting SAV or shellfish abundance and production in the Bay? How?

CPQ. 4. Do biological interactions regulate valued ecosystem components more than abiotic stressors, specifically in terms of:
. epiphytic or drift macroalgal inhibition of SAV; and
. predatory or parasitic inhibition of molluscan shellfish?

CPQ. 5. What statistically significant relationships describe the variation of SAV and molluscan shellfish stressors, as functions of the variation in values of freshwater inflow quantity, quality, and timing,
. for stressor values measured in freshwater inflows; and
. for stressor values measured in the Bay?

CPQ. 6. What changes in the quantity, quality, or timing of freshwater inflow must be achieved to relieve stressors regulating valued ecosystem components?

CPQ. 7. What are the sources, transport mechanisms, and residence times of pathogens in Bay waters and sediments?

CPQ. 8. What are the rates of pathogen bioaccumulation and depuration in Bay shellfish?

CPQ. 9. Is sea level rise a significant factor affecting valued ecosystem components in the Bay, in terms of:

- regulating Bay geometry, elevation, sedimentation, or tidal exposure,
- altering circulation, flushing, or salinity in open waters or tributaries; or
- decreasing maximum depths of submerged aquatic vegetation?

Physical and biological controlling processes, to which management actions should be directed, fall primarily upon freshwater inflows (for all three VEC), followed by nutrient and pathogen loadings (for SAV and shellfish, respectively). What scope exists for meaningful management actions will depend upon three findings of the research recommended in Part IV: the form of empirical relationships; collateral processes responsible for enduring ecological conditions that limit the scope of VEC response to management actions, and underlying geological structures, processes, and human alterations.

Part III identified a total of 14 different methods are pertinent to the research questions posed for Estero Bay. Methods fall into one of 6 general approaches:

- Statistical References (6 methods)
- Ecosystem Component Analysis (2 methods)
- Models (3 methods)
- Experimental Approaches (2 methods)
- Comparative Study, and
- Geographic Techniques.

In this fourth and final part of the project, the development process culminates in a set of recommended research projects presented below. Each has been crafted so as to support, supplement, or otherwise acknowledge other ongoing or planned research programs in or near Estero Bay, particularly the "Estuary Research Plan for the Upper East Coast and Lower West Coast," prepared by the South Florida Water Management District and Florida Center for Environmental Studies, and the "Compendium of Current Monitoring Programs in Charlotte Harbor and Complex Watersheds," prepared for the Charlotte Harbor National Estuary Program.

Eight research projects have been designed. Most are comprised of separate but related tasks --a total of 22 tasks are presented. Research projects address VEC status and trends, VEC stressors, and causal processes linking VEC to stressors. Titles of the projects include:

- SAV History and Trend Analysis.
- Molluscan History and Trend Analysis.
- Oligohaline Habitat History and Trend Analysis.
- History and trend Analysis for VEC Stressors.
- Ecological Studies of SAV Production and Regulation
- Ecological Studies of Shellfish Production, Regulation, and Sanitation.

% Sedimentology.

% Bay Water Quality

To the extent possible, each project follows a similar format, and some projects have been divided into project elements or have been supplemented with collateral investigations. A logical order for scheduling projects is given, and opportunities to link projects logistically are identified. Schedules recommended for these research projects are not intended to imply more than the optimal transfer of findings from one study to the next. No projects are compared in terms of scientific rank or merit-- all are considered necessary and sufficient to produce new, basic insights to Estero Bay that are directly applicable to the Bay's management needs.

Project scopes of work may be thought of as the technical elements for "Requests for Technical Proposals" available to the South Florida Water Management District, Estero Bay Agency on Bay Management, Southwest Florida Regional Planning Council, Charlotte Harbor National Estuary Program, or other agency to employ in furtherance of the Estero Bay and Watershed Management and Improvement Plan. Applicants for funding should be expected to submit technical proposals rather than statements of qualifications, in order to take full advantage of different scientific approaches to each research project, and to provide reviewers with additional selection criteria, such as familiarity with Estero Bay.